

Finite-difference Solutions of the Alternate Turbopump Development High-pressure Oxidizer Turbopump Pump-end Ball-bearing Cavity Flows

by

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These analyses were undertaken to aid in the understanding of flow phenomena in the Alternate Turbopump Development (ATD) High-pressure Oxidizer Turbopump (HPOTP) Pump-end ball bearing (PEBB) cavities and their roles in turbopump vibration initiation and bearing distress. This effort was being performed to provide timely support to the program in a decision as to whether or not the program should be continued.

In the first case, it was determined that a change in bearing throughflow had no significant effect on axial preload. This was a follow-on to a previous study which had resulted in a redesign of the bearing exit cavity which virtually eliminated bearing axial loading.

In the second case, a three-dimensional analysis of the inner-race-guided cage configuration was performed so as to determine the pressure distribution on the outer race when the shaft is 0.0002" off-center. The results indicate that there is virtually no circumferential pressure difference caused by the offset to contribute to bearing tilt.

In the third case, axisymmetric analyses were performed on an outer-race guided cage configuration to determine the magnitude of tangential flow entering the bearing. The removed-shoulder case was analyzed as was the static diverter case. A third analysis where the preload spring was shielded by a sheet of metal for the baseline case was also performed. It was determined that the swirl entering the bearing was acceptable and the project decided to use the outer-race-guided cage configuration.

In the fourth case, more bearing configurations were analyzed. These analyses included thermal modeling so as to determine the added benefit of injecting colder fluid directly onto the bearing inner-race contact area. The results of these analyses contributed to a programmatic decision to include coolant injection in the design.

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FINITE-DIFFERENCE SOLUTIONS OF THE ALTERNATE TURBOPUMP HIGH-PRESSURE OXIDIZER TURBOPUMP PUMP-END BALL-BEARING CAVITY FLOWS

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Huntsville, Alabama
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OVERVIEW

- Introduction
- Objective
- Approach
- Results
- Future work



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INTRODUCTION

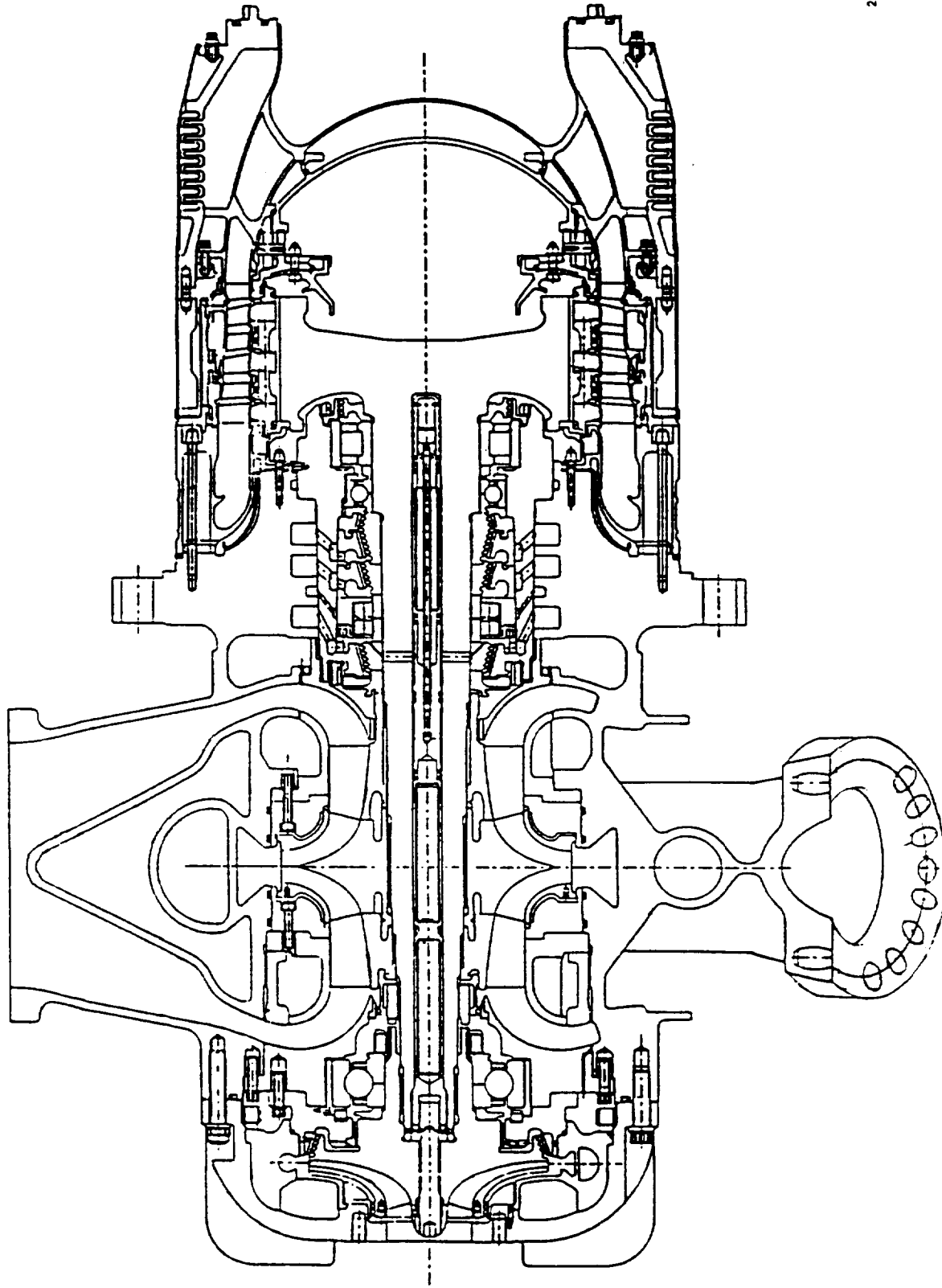
- Distress (increased temperature rise across bearings, high wear rate) observed in pump-end ball bearings in testing at Pratt & Whitney
 - Possible cause is loss of preload on the bearing
 - Second possible cause is loss of solid-film lubricant transfer to bearing contact areas because bearing outer-race tilt causes excessive ball temperature, which inhibits lubricant transfer
 - ◊ One potential agent for bearing tilt is asymmetric pressure loading on bearing
 - Third possible cause is inadequate cooling
- Some design changes implemented to mitigate distress
 - Move bearing cage to outer race to increase throughflow of fluid to inner-race contact areas
 - Remove material from inlet-side inner-race shoulder to increase flow to inner-race contact areas
 - Inject cooler flow near inner-race contact areas to reduce ball temperatures
 - Silicon nitride balls



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ATD SSME High Pressure Oxidizer Turbopump

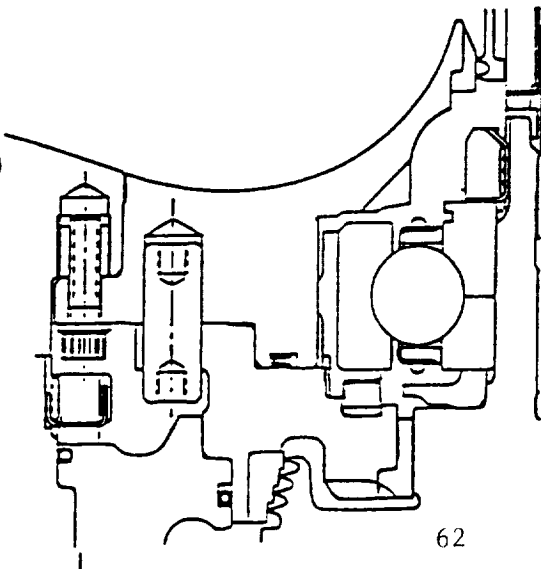




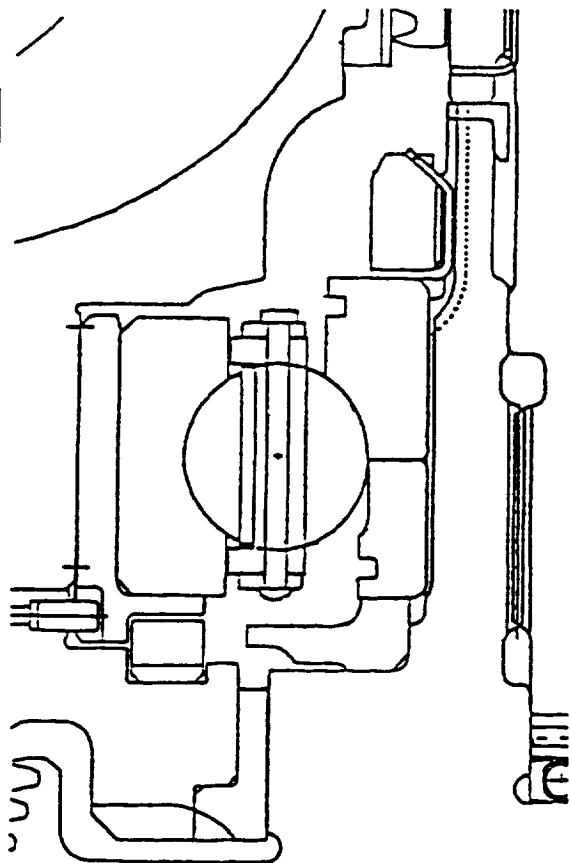
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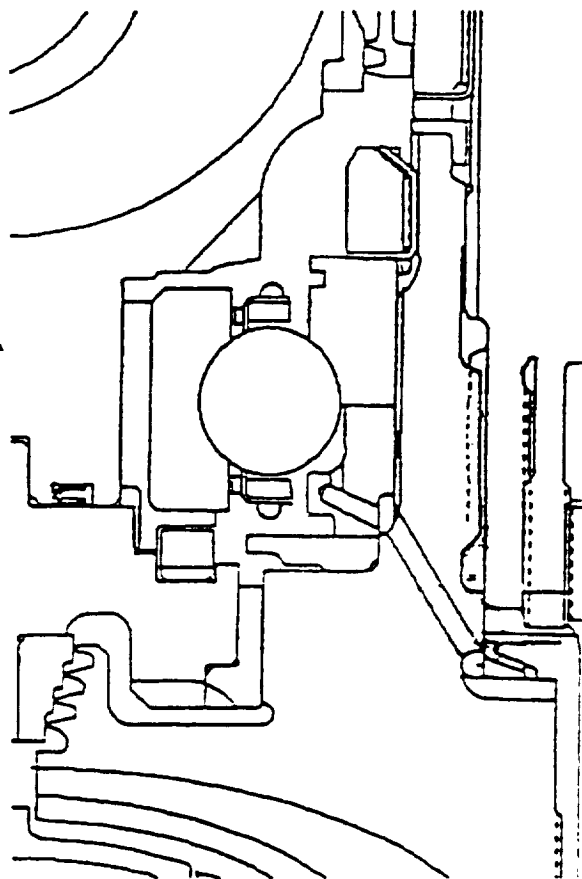
Baseline Configuration



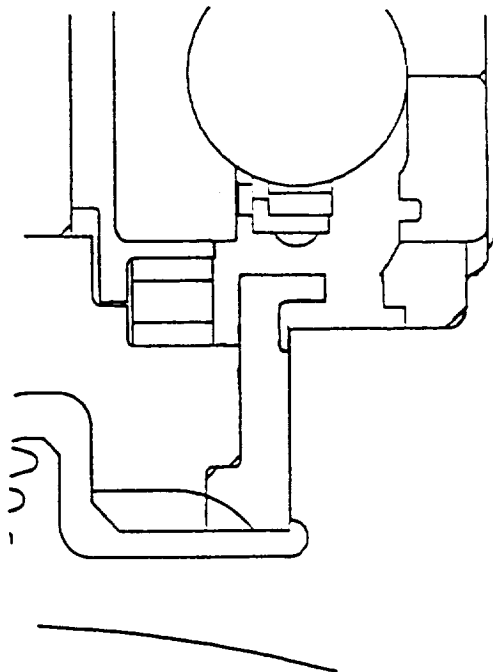
Removed Race Shoulder




Inner Race Injection



Static Diverter



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OBJECTIVE OF CFD ANALYSIS

- Determine effect of flow rate upon axial preload
- Quantify pressure field asymmetry due to rotor offset as cause of bearing tilt
- Determine effect of design changes upon bearing inlet swirl (viscous heating)
- Quantify effectiveness of design changes to enhance cooling




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APPROACH

- All analyses
 - K- ϵ turbulence model with wall functions
 - Neglected ball
 - Incompressible
 - Fixed inlet velocity field
- Effect on axial preload
 - Previous analysis indicated at 9 pps flow rate through bearing, pressure forces on inlet and outlet faces of bearing balanced such that preload was unaffected
 - Analyzed axisymmetrically and isothermally with finite-difference Navier-Stokes code (FDNS) and finite-volume Navier-Stokes co-located code (REFLEQS)
 - Analyzed for 15 pps flow rate to augment previous 9 pps analysis
- Pressure field asymmetry
 - Analysis of inlet cavity with 0.0002" shaft static offset and flow rate of 15 pps
 - Three-dimensional isothermal analysis using FDNS

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APPROACH (continued)

- Asses bearing design effects on bearing inlet swirl
 - Analyses of inlet cavity with outer-race-guided cage with flow rate of 15 pps
 - Utilized three configurations
 - Axisymmetric isothermal analysis using FDNS
- Cooling enhancement
 - Analyses of inlet cavity for outer-race-guided cage configuration
 - ◇ Lowered shoulder analyzed for three different ball/inner-race heat-generation levels with 15 pps through bearing
 - ◇ Injection cases analyzed for three different ball/inner-race heat-generation levels with 7.5 pps entering through seal (230 °R) and 7.5 pps injected through inner race (190 °R)
 - Axisymmetric thermal analyses using REFLEQS
 - Effectiveness determined by maximum temperature in bearing area



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RESULTS

- Change in flow rate does not affect axial preload
- No circumferential pressure field asymmetry due to shaft offset to contribute to bearing tilt
- Moving bearing cage to outer race increases inlet swirl
 - Baseline: bearing inlet swirl = 15 ft/sec
 - Removed race: bearing inlet swirl = 31 ft/sec
 - Shielded preload spring: bearing inlet swirl = 105 ft/sec
 - Static diverter: bearing inlet swirl = 55 ft/sec
- For silicon nitride balls, cooling enhancement keeps ball temperatures in desirable range
 - For inner race guided cage with no EHD, maximum temperature 325 °R
 - For outer race guided cage:

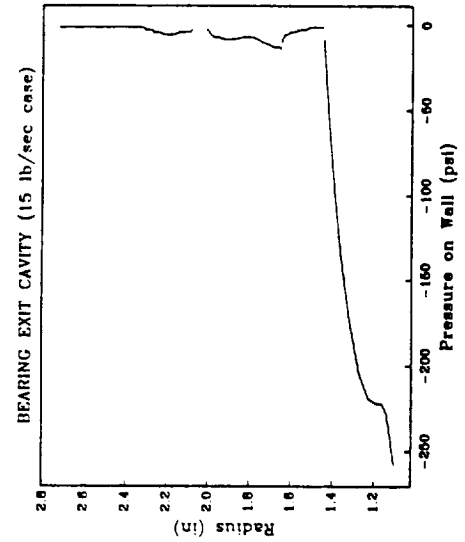
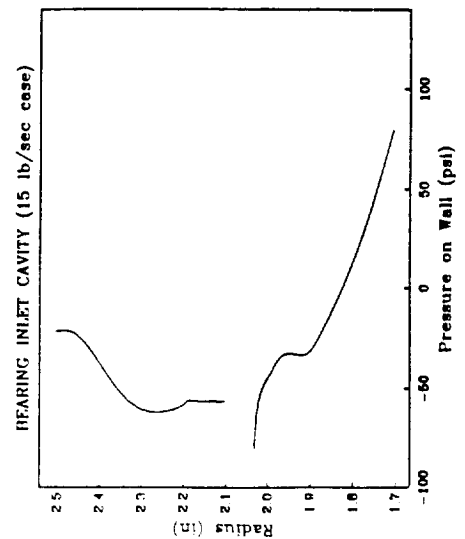
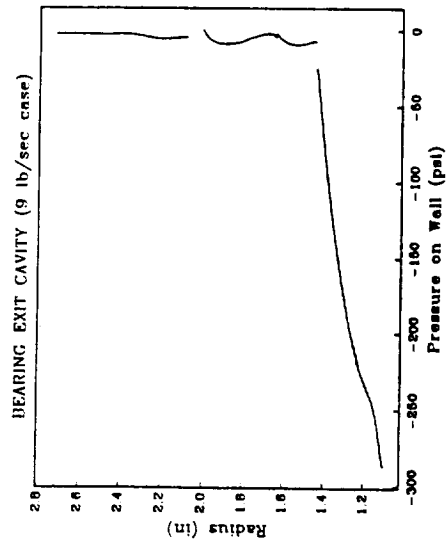
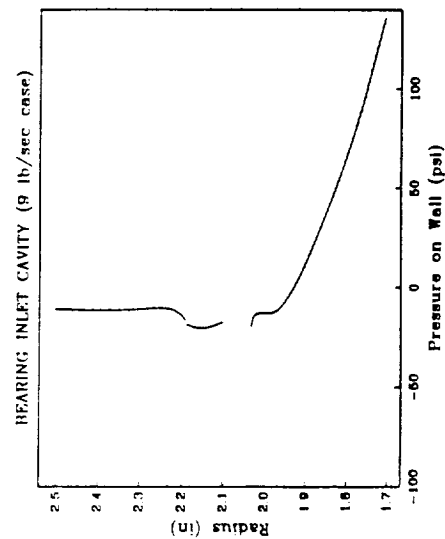
<u>Elastohydrodynamic film (Q)</u>	<u>Lowered shoulder</u>	<u>Coolant injection</u>
None (0.56 Btu/sec)	255 °R	213 °R
Partial (0.23 Btu/sec)	240 °R	204 °R
Full (0.028 Btu/sec)	231 °R	198 °R



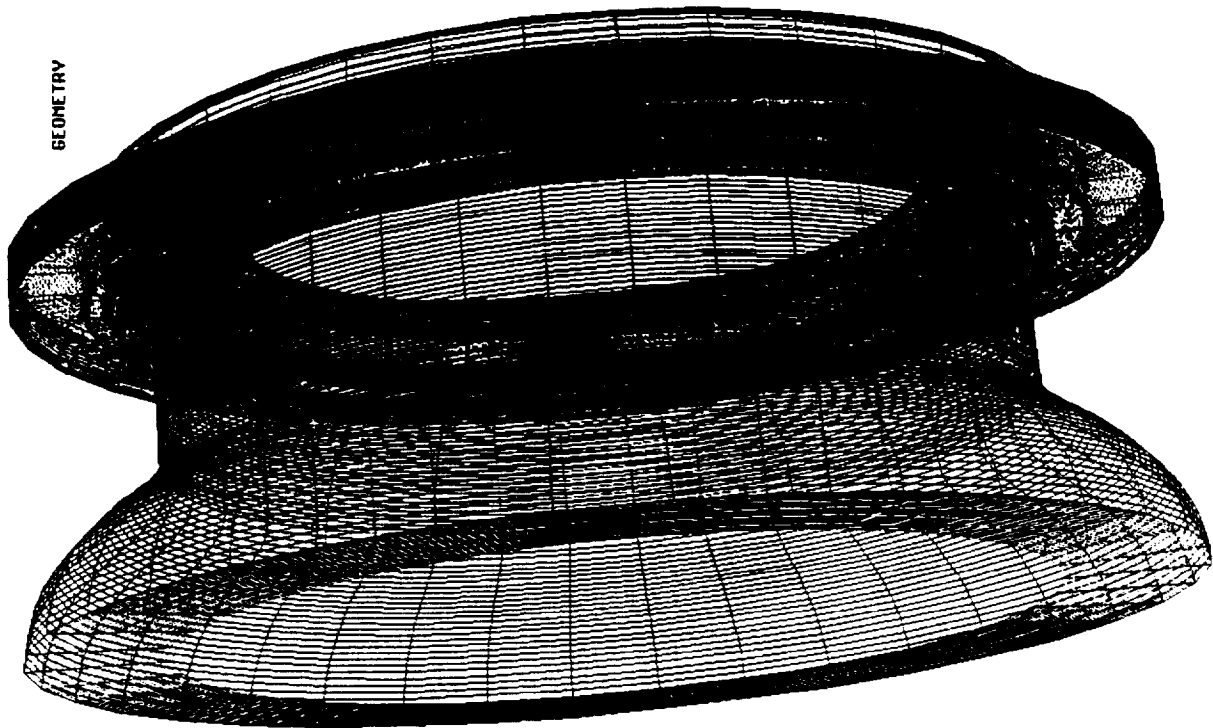
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Bearing-face Pressures



GEONE TRV

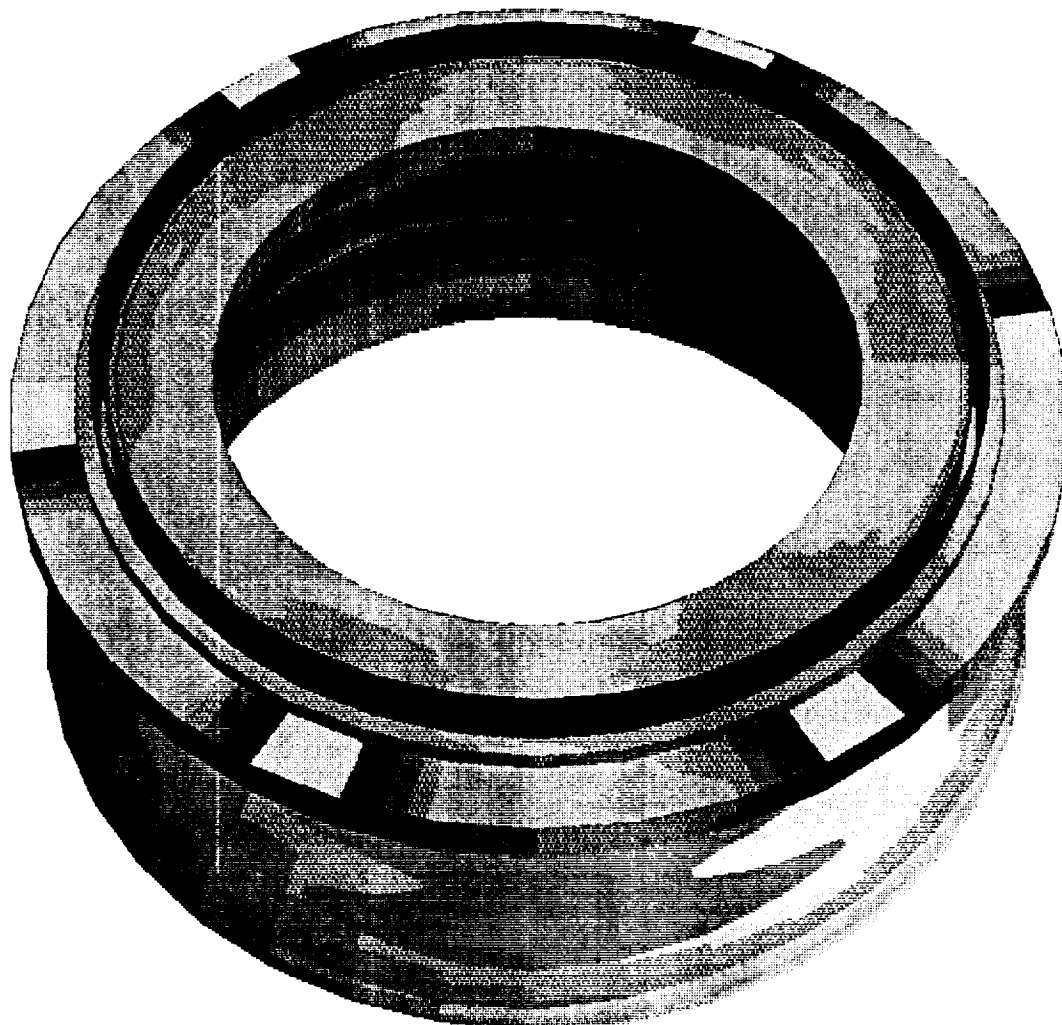


fort.1.1mg

51x25x37
51x21x37
28x45x37
93x11x37
32x61x37
67x15x37
46x15x37
37x31x37
33x25x37
GRID 1
GRID 2
GRID 3
GRID 4
GRID 5
GRID 6
GRID 7
GRID 8
GRID 9

STATIC PRESSURE (psf.)

Baseline



CONTOUR LEVELS
 330000.0
 335000.0
 340000.0
 345000.0
 350000.0
 355000.0
 360000.0
 365000.0
 370000.0
 375000.0
 380000.0
 385000.0
 390000.0
 395000.0
 400000.0
 405000.0
 410000.0
 415000.0
 420000.0
 425000.0
 430000.0
 435000.0
 440000.0
 445000.0
 450000.0
 455000.0

MACH
 ALPHA
 Re -
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 GRID 2
 GRID 3
 GRID 4
 GRID 5
 GRID 6
 GRID 7
 GRID 8
 GRID 9
 GRID 10
 GRID 11
 GRID 12
 GRID 13
 GRID 14
 GRID 15
 GRID 16
 GRID 17
 GRID 18

0.010
 0.00 DEG
 1.10x10⁻⁶
 51x25x19
 51x21x19
 28x45x19
 93x11x19
 32x61x19
 67x15x19
 46x15x19
 37x31x19
 33x25x19
 51x25x19
 51x21x19
 28x45x19
 93x11x19
 32x61x19
 67x15x19
 46x15x19
 37x31x19
 33x25x19

W VELOCITY
Slinger
With Preload Spring

CONTOUR LEVELS

- 0.0
- 10.0
- 20.0
- 30.0
- 40.0
- 50.0
- 60.0
- 70.0
- 80.0
- 90.0
- 100.0
- 110.0
- 120.0
- 130.0
- 140.0
- 150.0
- 160.0
- 170.0
- 180.0
- 190.0
- 200.0
- 210.0
- 220.0
- 230.0
- 240.0
- 250.0
- 260.0
- 270.0
- 280.0
- 290.0
- 300.0
- 310.0
- 320.0
- 330.0
- 340.0
- 350.0
- 360.0
- 370.0
- 380.0
- 390.0
- 400.0

fort.2.ing

- 0.010
- 0.00 DEG
- 1.10x10**6
- 51x25
- 51x21
- 28x45
- 93x11
- 32x61
- 57x15
- 46x15
- 37x31
- 33x25
- 70x50
- MACH
- ALPHA
- Re
- GRID 1
- GRID 2
- GRID 3
- GRID 4
- GRID 5
- GRID 6
- GRID 7
- GRID 8
- GRID 9
- GRID 10

W VELOCITY
Slinger
With Shielded Preload Spring

CONTOUR LEVELS

0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
240.0
250.0
260.0
270.0
280.0
290.0
300.0
310.0
320.0
330.0
340.0
350.0
360.0
370.0
380.0
390.0
400.0

0.010
0.00 OFG
1.10x10**6
51x25
51x21
28x45
93x11
32x61
57x15
46x15
33x25
70x50

HAICH
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Re
GR10 1
GR10 2
GR10 3
GR10 4
GR10 5
GR10 6
GR10 7
GR10 8
GR10 9

fort.2. img

W VELOCITY
Static Diverter
With Preload Spring

MACH
ALPHA
Re
GRID 1
GRID 2
GRID 3
GRID 4
GRID 5
GRID 6
GRID 7
GRID 8

0.010
0.00 DEG
1.10x10⁻⁶
51x25
24x28
28x74
93x50
31x47
46x15
33x25
37x31

CONTOUR LEVELS

-10.0

0.0

10.0

20.0

30.0

40.0

50.0

60.0

70.0

80.0

90.0

100.0

110.0

120.0

130.0

140.0

150.0

160.0

170.0

180.0

190.0

200.0

210.0

220.0

230.0

240.0

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270.0

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340.0

350.0

360.0

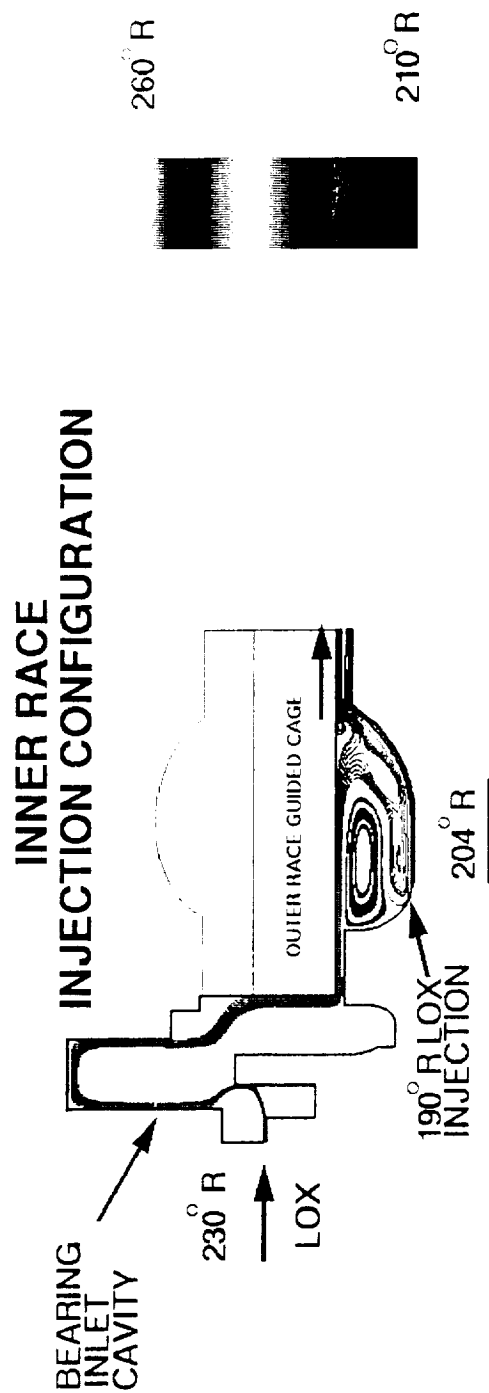
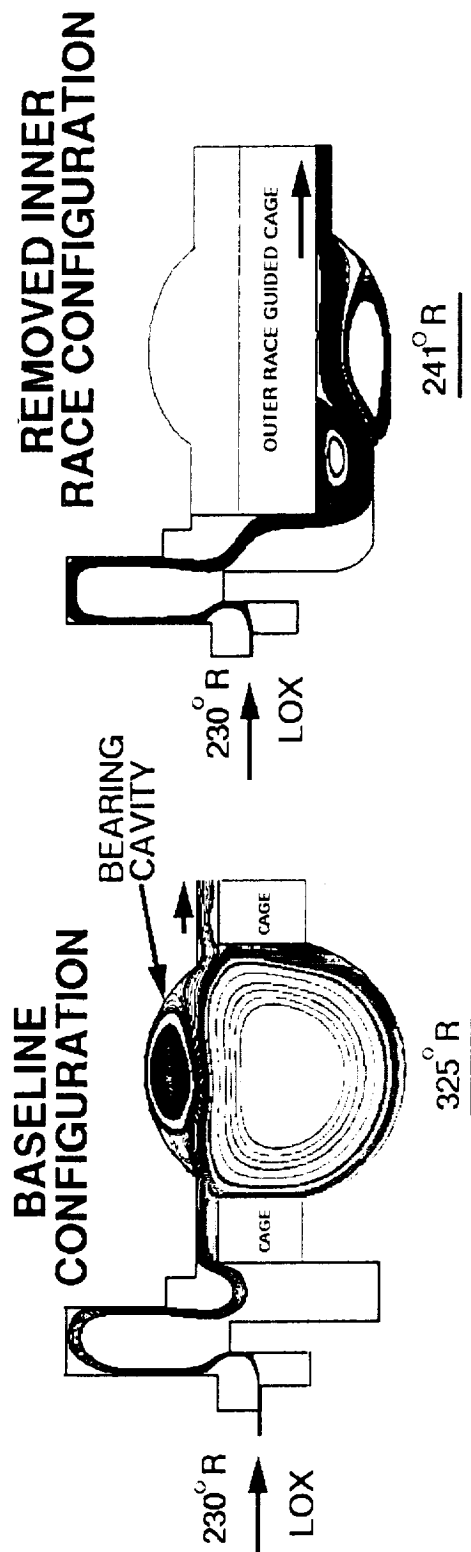
370.0

380.0

390.0

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CFD ANALYSIS OF ATD BEARING FLOWS FLOW STREAMLINES COLORED BY FLUID TEMPERATURE



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Future Work

- Optimizing inner-race injection design
 - Sweep angle
 - Injection flow rate
 - Axial flow angle
 - Other possibilities
 - ◇ Shoulder height
 - ◇ Hole location, size, number